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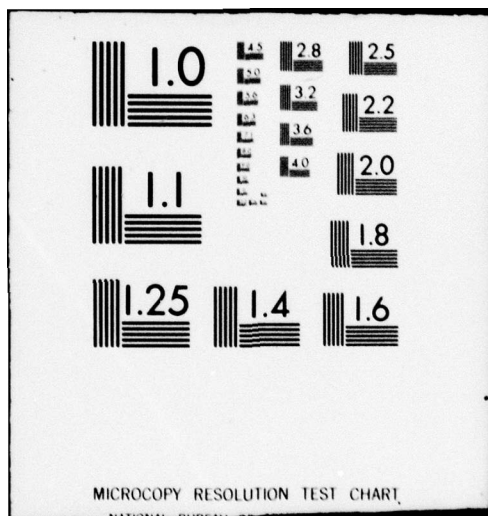
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WHY NOT SAILS?

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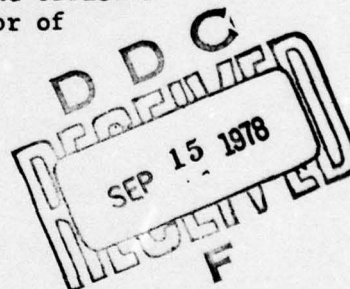
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Abstract

With the shortage of fossil fuels becoming a serious problem and the high cost and environmental hazards of nuclear propulsion, it appears to be a good time to go back and take a hard look at the use of sails as the device and wind as the energy source for ship propulsion. (In the interest of adding credence to what may be considered a questionable endeavor, it should be noted that serious studies are being made both in Britain and West Germany concerning the practicality of sail propulsion for commercial vessels.)

The paper reviews the history of sails as a means of propulsion, the capabilities and limitations of modern sailing ship designs with both conventional displacement hulls and unconventional hull forms such as semi-submersible and hydrofoil supported considered.

A variety of designs to suit naval and commercial applications are provided for further consideration.

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Notation and Glossary

Notation

LWL - Length, Waterline
V - Velocity in Knots (Nautical Miles/Hour)
Speed/Length Ratio - V / LWL

Glossary

Aerohydrofoil - Sailing craft developed by Bernard Smith which uses an airfoil or wing for a sail and hydrofoils for a hull.

Aero-SWATH - Sailing craft with a wing sail and a SWATH.

ASW - Anti-Submarine Warfare.

Gale Force - 55 to 75 mile/hour wind.

Point - Sail close to the wind (almost into the wind).

Reach - Sail with the wind at about a right angle to the vessel.

Run - Sail away from the wind.

RUSH - RUdder Shaped Hull - A low resistance hull form.

Sea State - A scale of 1 to 10 ranging from near calm to typhoon generated waves. Sea state is based on wave heights and frequencies.

SWATH - Small Waterplane Area Twin Hull - A low resistance hull form.

Tack - When sailing, to move the bow into the wind such that the wind shifts from one side of the sails to the other.

Tons - For purposes of this paper - long tons.

Wetted Surface - The area of the hull and appendages below the waterline.

Why Not Sails?

Introduction and Background

With the shortage of fossil fuels becoming a serious problem and the high cost and environmental hazards of nuclear propulsion, it would seem to be a good time to re-evaluate the use of sails as a primary or auxiliary means of propulsion for both military and commercial water-borne craft.

The evolution of propulsion of ships and boats has been a long, and for some time, an extremely slow process. Long before recorded history we can assume that man, with his superior intelligence, started by merely drifting with the current on a log. In a relatively short time he found that by paddling with his hands and later with wooden slabs (paddles), he could control direction and, if he exerted some effort, could move his log in any direction in still water by paddling. Once having developed the paddle he rarely went away from shore without one because, until engines and motors were developed to propel craft, he found the paddle the only device which could be relied on to ultimately get him home regardless of current, wind, or weather. Even today most users of small boats carry a paddle or oars as an auxiliary propulsion device.

The arrival of sail provided the boatman with a useful propulsive capability but it also created new problems. Early sailing rigs could not go upwind because they used sail designs which ~~would not~~ could not provide the ability to "point" into the wind. (See glossary for definitions.) The most common of the early sail forms was the square sail which, at best, could either go away from or sail ~~parallel~~ ^(perpendicular) to the wind ("run" or "reach").

In time the two features which were required to go to windward came into use: Some sort of keel to resist the sideward force of the wind on a "tack;" and the use of some form of fore and aft sails which employed the airfoil lift concept for the provision of motion into the wind. The lateen sail appeared in about the year 200 B.C., and remained the prominent fore and aft sail, usually used in conjunction with square sails, until 1700 A.D., when the jib appeared. Later, square sails gave way to gaff-rigged sails and finally gaff-rigged sails were displaced by the development of the familiar Marconi sail which is the most prevalent sail in use by the yachting world today. (See Figure 1 for sail forms.)

In the late 19th century sail was usurped by the steam engine, first driving paddle wheels and later propellers. For a time sail was prime and steam was the auxiliary. Later steam was prime and sail was the auxiliary propulsion source. By the end of the 19th century, sails had all but disappeared in commercial applications and had completely disappeared in military applications other than for training.

The steam engine, fed by a coal-fired, fire tube boiler, gave way to the steam turbine fed by an oil-fired, water tube boiler in the early years of the 20th century. In more recent years, the water tube boiler/turbine combination has been joined by the diesel engine, the nuclear steam generator, and the gas turbine as common propulsion sources.

Hull forms have evolved perhaps even more slowly than propulsion systems. Three or four forms have been in use for most of recorded history. Probably the most common of these has been the mono-displacement hull, at least in Atlantic and Mediterranean waters. However, the proa (i.e., outrigger canoe) and its very close cousin, the catamaran, have existed in Pacific waters for an equally long period. The trimaran is basically a double proa and the planing hull is a variation on the mono-displacement hull. Little definitive work on other than the above forms has been done until recent years (i.e., since World War II). Three or four of these recent designs show considerable promise in minimizing the basic problem of overcoming the bow wave to permit higher speeds with less power than the older forms require. The surface effect ship (SES) does not appear to be a useful form if sail is to be the prime propulsion source because of its dependence on considerable mechanically generated low pressure air to lift the hull and its lack of resistance to side forces. However, the hydrofoil, and the mono- and twin-hulled semi-submersibles along with a variety of hybrid designs appear to have considerable potential for efficient sail propulsion.

Problems

Perhaps we should look first at reasons why sail is no longer used in commercial and military applications. The first and perhaps most obvious problem is the wind, or more to the point, the lack of wind. The wind seldom blows at the right time, in the right direction, and at the desired speed. However, it does blow over most of the ocean most of the time and usually at velocities in excess of ten knots and less than 30 knots.

The major problem commercial sailing ships had with the wind was the direction. Historically, the commercial sailing ship followed the "trades" or trade winds, not because they wanted to, but because they had to. The relative inability of sailing ships to point into the wind was perhaps their biggest weakness.

The next problem to consider was the large crew required to man sailing ships of the designs used commercially. The large number of sails provided to catch the wind and make the most speed possible also required a small army of deckhands to set and strike.

The third major problem is with the limitations of traditional hull forms which meant a sailing ship had to be very long to make speeds competitive with steam ships. Virtually all cargo-carrying commercial sailing vessels used mono-displacement hulls which with sail propulsion could not exceed a speed length ratio of 1.4 to 1.5 and could only attain such speed under ideal conditions of wind velocity and direction. However, World War I destroyers could attain a speed length ratio of 2 any time and in any direction except under storm conditions (sea state 6 or higher) which occur less than an average of 10% of the time on the world's oceans. The best speed the famous clipper ships could make was a formidable 21 knots credited to the JAMES BAINES in the late 19th century. This record and others near it were made on a broad reach before gale winds.¹ In more recent years both a small catamaran and a small hydrofoil supported sailboat attained speeds slightly over 30 knots.^{1,2} It is interesting to note that the foil boat used surface piercing foils and conventional sails and the catamaran used a rigid airfoil as a sail.

Advantages of Sail

In spite of the above problems, sail has many advantages that may far outweigh the problems. From a purely tactical point of view the quiet movement, without the clatter of machinery or the cavitation of propellers make the sailing ship an ideal Anti-Submarine Warfare (ASW) platform. Both its ability to be relatively difficult to find because of its lack of self-generated noise, and the significant increase in its ability to hear without the sounds being confused or masked by own ship's noise, make it uniquely desirable. This is especially true considering that this noiseless state is generally available over the full speed range of the sailing vessel.

Another advantage of the sailing ship is its endurance when compared to fossil-fueled ships. This advantage is very significant in some mission scenarios such as Indian Ocean operations or in war scenarios with low ordnance consumption characteristics. Obviously, under a short term, high ordnance consumption scenario with short supply lines, this advantage would not be very significant.

Without benefit of extensive study, it would seem reasonable that if manning were equal or favored sailing vessels, the cost of owning and operating a commercial or military sailing vessel would be less than the cost of a fossil fuel driven ship. Typically, commercial-type ships' costs for hull and machinery are about equal and the life cycle cost of operating and maintaining the machinery plant exceeds the cost of hull maintenance by a considerable margin.

Speed without cost or endurance penalty is another plus for sailing ships. The ship can be operated at full speed for as long as desired without worrying about fuel cost or need for frequent fuel resupply. High speed with fossil fuel propulsion also tends to be hard on machinery and the ship in general, whereas speed under sail is not particularly damaging.

One other attractive feature of sailing ships in the military role is their ability to move without consuming limited energy sources. Even if sail were an alternate to fossil fuel propulsion for military vessels, the sails would permit conservation of fossil fuel in peacetime training operations, saving the available fossil fuel for wartime conditions.

Ongoing Development

There is apparently little work being done to establish whether or not sail is a viable alternative for commercial or military applications. The British Admiralty was studying the problem and a West German idea called Dyna₃Ship is being promoted by a California corporation of the same name.⁴ The Dyna Ship idea is⁵ the brain child of a Dr. Prolss at the Schiffbau Institute of Hamburg. Considerable development has been put into the Dyna Ship concept, including scale model tests and detailed analysis of trade routes for its potential use.

The Dyna Ship is basically a square rigger with a gimmick -- the sails roll up into the mast. The device is powered to minimize manning requirements. Obviously this type of rig would have to follow trade routes with reliable trade winds as the sail design virtually precludes upwind motion. Hugh Lawrence in Sausalito, California, is working on a similar project. However, he is using a Marconi rig.⁵ Both Prolss and Lawrence claim average speeds of 12 knots over selected routes. Alan Villiers, probably the world's authority on tall ships, has commented on the commercial use of sail and has endorsed going back to "... a proper sailing ship, not a monstrosity." He neither likes any of the new ideas nor does he think sail has much chance of coming back as a commercial success.

In his excellent book, The 40-Knot Sailboat, Bernard Smith, a physicist with the Navy at China Lake, a student at the Naval War College, and Chief Engineer of the Bureau of Naval Weapons in the 1960's described his Aerohydrofoil. This unique vessel combines the technology of the airfoil and the hydrofoil into a virtually hull-less sailing craft with the potential for sailing at speeds of up to 40 knots from 60 to 120 degrees off a 20 knot wind; and at 20 knots as little as 30 degrees off the wind. (See Figure 2.) Unfortunately Mr. Smith's ideas have apparently not been fully tested. More recently very similar ideas have been studied and tested. Walter J. Johnson of Boeing in his paper to the AIEE/SNAME Symposium on Sailing in 1975 called RUSH Geometries⁶ his studies and tests of RUdder Shaped Hull (RUSH) vehicles which used an airfoil/hydrofoil concept. C. L. Strong in his article in the Scientific American's "The Amateur Scientist" series titled The Ultimate In Sailing Is A Rig Without A Hull also used an airfoil/hydrofoil concept except that Strong used a parafoil (parachute airfoil) instead of a rigid airfoil.

Little or no feedback has been available from the British Admiralty study in the last year or two, and it now appears that no government is seriously looking at research into the practical use of sail in this century.

Discussion

An in-depth analysis of the potential uses for sail propulsion would probably lead to the following conclusions:

- . To be accepted, sail propulsion schemes will need to provide for capability of at least 15 knots. At speeds lower than 15 knots most mechanically powered commercial and military ships become very efficient and the issue of fuel consumption would, therefore, be much less significant.
- . To be accepted, sail propulsion schemes must use an equal or lower manning level than fossil or nuclear fuel propulsion systems. Manning has become the controlling cost in ship's operation and therefore greater manning for sail would negate its use because of simple economics.
- . To be accepted, sail propulsion schemes must be capable of moving the ship at reasonably high speeds into, or nearly into, the wind. One possible exception would be commercial ships developed for the limited number of trade routes where the prevailing, or trade winds, are compatible with upwind limitations of designs such as Dyna Ship.
- . To be accepted, sail propulsion will require an auxiliary backup system capable of delivering a 15 knot or greater speed capability. The wind doesn't always blow.

Other mission or route considerations which would affect the selection of a particular hull/sail configuration would be:

- o Platform size
- o Cargo volume
- o Displacement
- o Speed requirements over 15 knots

In most cases, the speed desired and the speed limitations of monodisplacement hulls can be expected to be incompatible. To attain a speed of 15 knots under any condition of wind velocity and relative direction would require that the hull be at least 120 feet long, (LWL), and that the wind be gale force and abeam so that reaching (the best sailing speed condition) was the sailing point. Under normal wind conditions and using conventional sails a speed/length ratio of about .6 would be required. To attain a speed of 15 knots at a speed/length ratio of .6 a water line length of about 625 feet would be required which would be excessive in many cases.

Catamarans, proas, and new ideas such as the Aero-hydrofoil have considerable potential for small, relatively light displacement requirements, especially where speeds over 15 knots are desired. The Aero-hydrofoil, for example, theoretically has the potential for use as a high speed ASW search vehicle which would be inexpensive, difficult to detect, and very efficient because of its low noise when used in a passive (listening only) mode.

As size and displacement requirements increase we can reasonably expect that the conventional hydrofoil craft (with either surface piercing or submerged foils) would be attractive, as indicated by studies and experiments with small ladder-type surface piercing foil boats driven by sail where speeds up to 30 knots were attained.

As displacement requirements increase, the foil concept becomes impractical because the foil area requirements increase by the square of displacement. Therefore, at larger displacements we must discard foils and find some other way to overcome the speed limitation of monodisplacement hulls. One of the more recently developed forms which seems to have the desired characteristics is the semisubmersible. The ratio of wetted surface to displacement is high for semisubmersibles as compared to displacement hulls, but the ratio of wetted surface to displacement decreases as displacement increases. The wave making resistance of these designs is minimal. The greater the distance between the surface and the bulk (or bulb) of the underwater hull, the lower the wave making resistance until the underwater hull is about three times its diameter below the surface where the wave propagation of the bulb is virtually zero. Because of their wetted surface semisubmersible hull forms suffer from poor propulsive efficiency when operating at low speeds. However, with sails this penalty tends to be insignificant because the wind is free. The semisubmersible can be built in either a mono or twin hull configuration. The monohull semisubmersible is sometimes referred to as a Small Waterplane Area Single Hull or SWASH form whereas the twin hull is usually called a Small Waterplane Area Twin Hull or SWATH form. The selection of SWASH or SWATH forms will be dictated by a variety of considerations.

The monohull has the advantages of lower wave making resistance and lower wetted surface for equal displacements. In addition, the monohull has considerably less beam than a SWATH configuration which becomes critical when the SWATH's beam exceeds dry dock and canal limitations. The advantages of SWATH configurations are their inherent stability, a large beam providing a large topside area, and the ease with which twin propellers can be fitted. With sail for propulsion, stability may be critical, making the SWATH form more desirable.

Turning to sail design as a consideration, we need to decide whether conventional cloth sails or some sort of rigid airfoil is the best approach to sail propulsion. A review of the literature indicates that rigid or semirigid airfoil sections have significant advantages

over the more traditional battened canvas (Dacron) sails.^{1,6} Perhaps the most significant of these advantages is the improved performance possible with airfoils. Figure 2 is a plot of the theoretical speed characteristics of an airfoil fitted sailing vessel with virtually no wave making tendencies (the Aerohydrofoil)¹ at various headings relative to the wind. It is interesting to note that at a wind velocity of 13.4 knots the theoretical max velocity of the Aerohydrofoil is about 32 knots at 90 degrees off the wind, at 45 degrees off the wind a velocity of over 21 knots results, and at 15 degrees off the wind the craft is still moving, albeit at about seven knots. At a 15 degree angle off the wind, a conventional sail would be "in irons" (would have lost its shape and be flapping). When sailing at 21 knots, 45 degrees off this 13.4 knot wind, speed made good up wind is about 14 knots or faster than the wind when going into the wind. Another advantage of airfoils is the low manning requirements inherent in their design.

Proposals and Conclusions

A review of the available literature indicates that there are modern techniques available which, on a small scale, have proven and in theory hold promise, for sail as a practical method of craft and probably ship propulsion at speeds equal to or greater than the velocity of the wind regardless of heading; that speeds more than twice wind velocity are possible on a reach; and that to attain most of those velocities requires the use of hull forms which do not create significant bow waves.

Another factor which becomes apparent is that a single basic design of hull and sail is probably not compatible with the full range of characteristics which can be postulated for sail driven vessels. Therefore, I propose a series of different designs as candidates for sail propulsion as follows:

- . A light, fast vessel of less than 100 tons - the Aerohydrofoil seems most suited to this mission area. It has a potential speed almost three times wind velocity at its best, and a speed greater than the wind at its least practical heading. Its major drawbacks are its relatively slow rate of development which would require considerable funding to improve, and its incompatibility with conventional forms of auxiliary propulsion. A cursory review of the design indicates that an air drive might be practical. However, additional study would be required to verify this conclusion. Figure 3 is the inventor's sketch of what a practical Aerohydrofoil might look like. Commercial applications might be as an offshore drilling platform, personnel boat, or a high speed passenger ferry. Military applications might be ASW passive listening or general reconnaissance.
- . In the 100 to 500 ton range, and again assuming relatively high speed is desired, I believe a hydrofoil configuration such as is currently being used for the PHM with a single airfoil (wing) for a sail and gas turbo/electric auxiliary drive could be practical (see Figure 4). To compensate for the reaction of the wind force on the sail, either the foils would have to be designed to compensate or the angle of the wing with the deck would have to be adjustable, or perhaps both. To accommodate the wind, the wing would also have to be capable of being rotated to provide maximum velocity at all headings. Applications would be much the same as for conventional foil craft except that the high speed possible with conventional foil craft would not be possible under sail. It would be interesting to establish what would happen if the gas turbine/electric motor drive were used in parallel with the wing. Would performance exceed the performance possible with only one system in use or would the two propulsion systems work against each other?

- . If larger vessels (500 tons or greater) are desired and high speed is also required by cursory analysis indicates that a cross between the SWATH and the RUSH⁶ would be most suitable. A twin wing sail configuration appears most feasible. However, more extensive analysis might indicate that as many as four sails, or simply one, might be better. Figure 5 is my idea of what such a vessel might look like which I, for lack of a better name, call Aero-SWATH. Missions for the Aero-SWATH would include most ship missions except for those which could not accommodate the wing sails on deck, such as an aircraft carrier and those which do not need speed in excess of a speed length ratio of about .8.
- . There are many missions which do not require high speed and many of these missions could be met by universally mounting a wing sail on a conventional displacement hull. This might be an excellent way to minimize the impact of fuel shortages on peacetime military training.

The major problem with the use of sail for ship propulsion is the apparent lack of interest both in the commercial and military sectors of the world's economy. I find it difficult to understand how we can ignore the potential of wind driven ships considering the hazards and costs of nuclear propulsion and the costs and potential for future extinction of fossil fuel propulsion systems.

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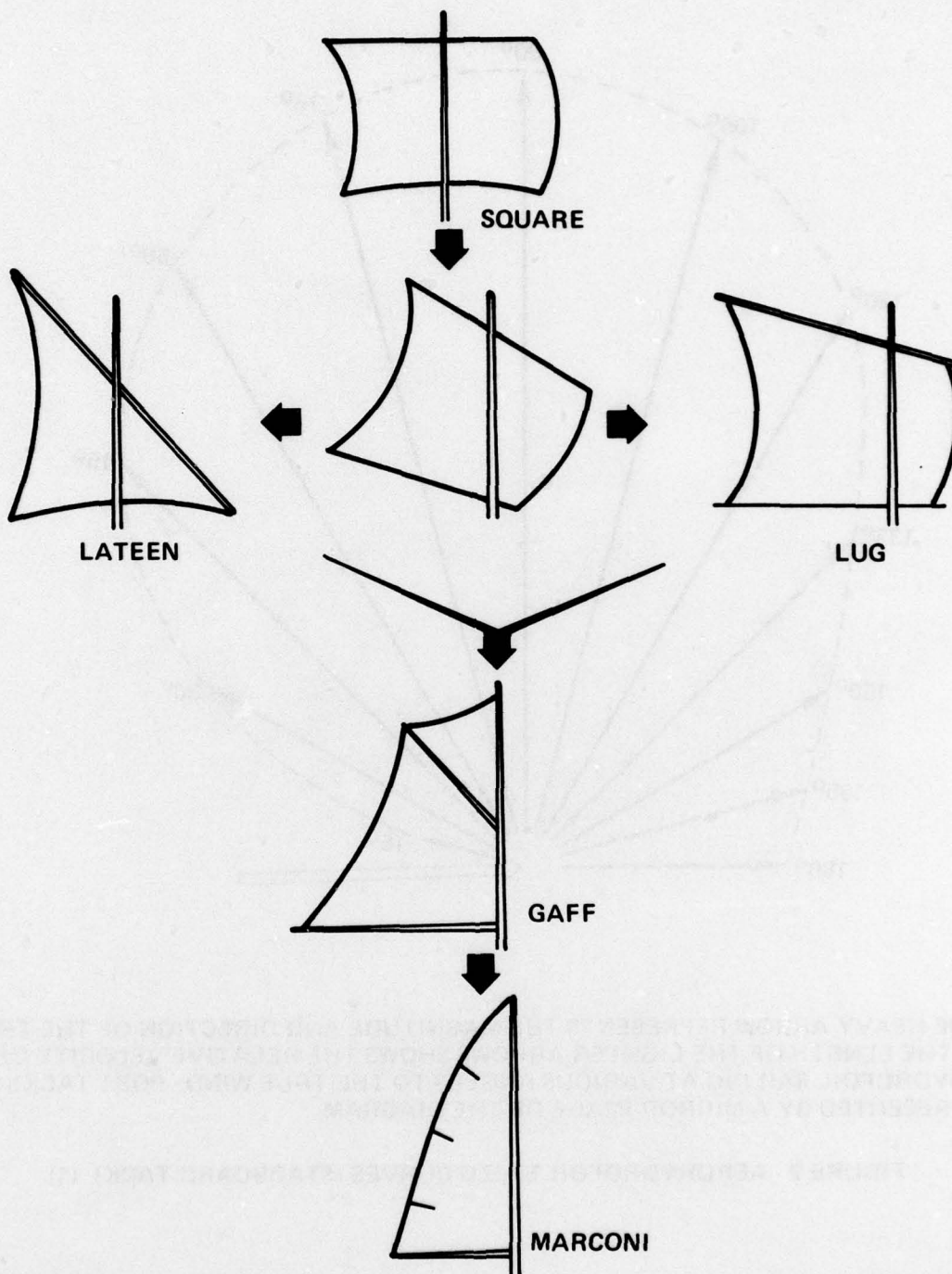
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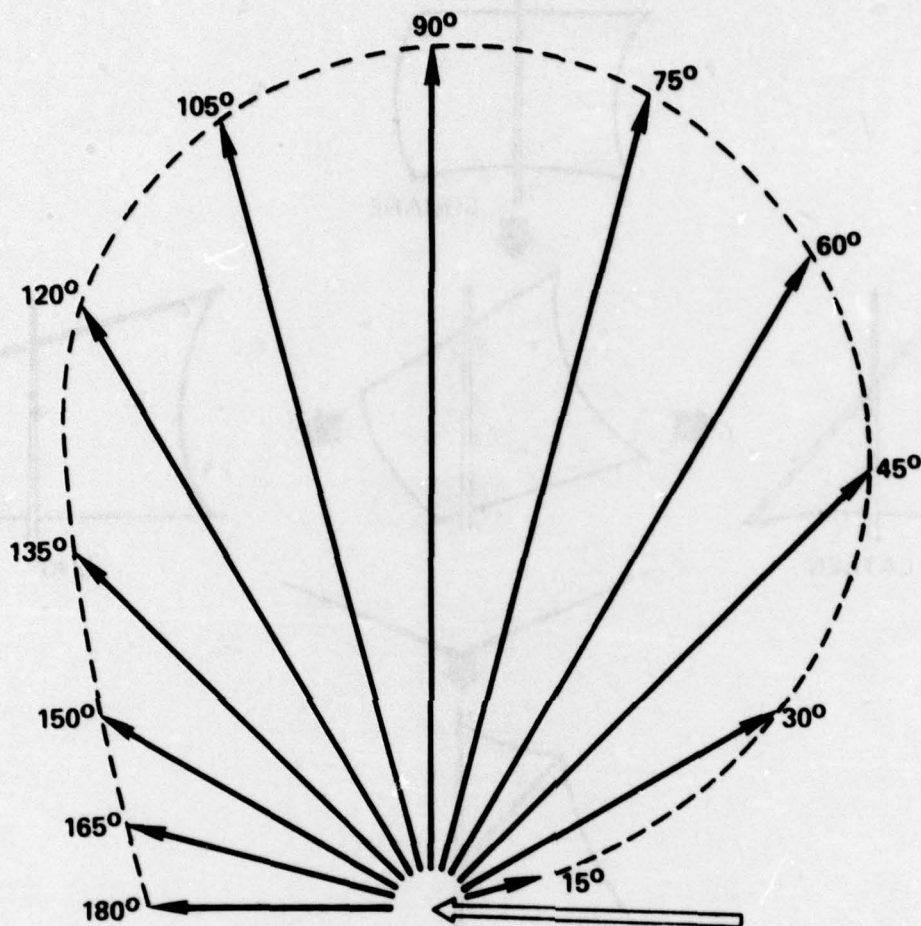
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ALL SAILS APPARENTLY HAVE THEIR ORIGIN IN THE SQUARE SAIL, WHICH IS STILL USED FOR SAILING DOWNWIND IN MANY PARTS OF THE WORLD. TO SAIL MORE EFFECTIVELY AGAINST THE WIND, LATEEN AND LUG SAILS WERE INVENTED EARLY IN SAIL-BOAT HISTORY. THESE LATER DESIGNS WERE "ASYMMETRICAL" IN THE SENSE THAT THE YARDS AND THE FABRIC WERE NOT DISTRIBUTED EQUALLY ON EACH SIDE OF THE MAST. THE MOST HIGHLY REFINED OF SUCH "FORE-AND-AFT" SAILS IS THE MARCONI.

FIGURE 1 - EVOLUTION OF SAILS (1)



THE HEAVY ARROW REPRESENTS THE MAGNITUDE AND DIRECTION OF THE TRUE WIND. THE LENGTH OF THE LIGHTER ARROWS SHOWS THE RELATIVE VELOCITY OF THE AEROHYDROFOIL SAILING AT VARIOUS ANGLES TO THE TRUE WIND. PORT TACKS WOULD BE REPRESENTED BY A MIRROR IMAGE OF THE DIAGRAM.

FIGURE 2 - AEROHYDROFOIL SPEED CURVES (STARBOARD TACK) (1)

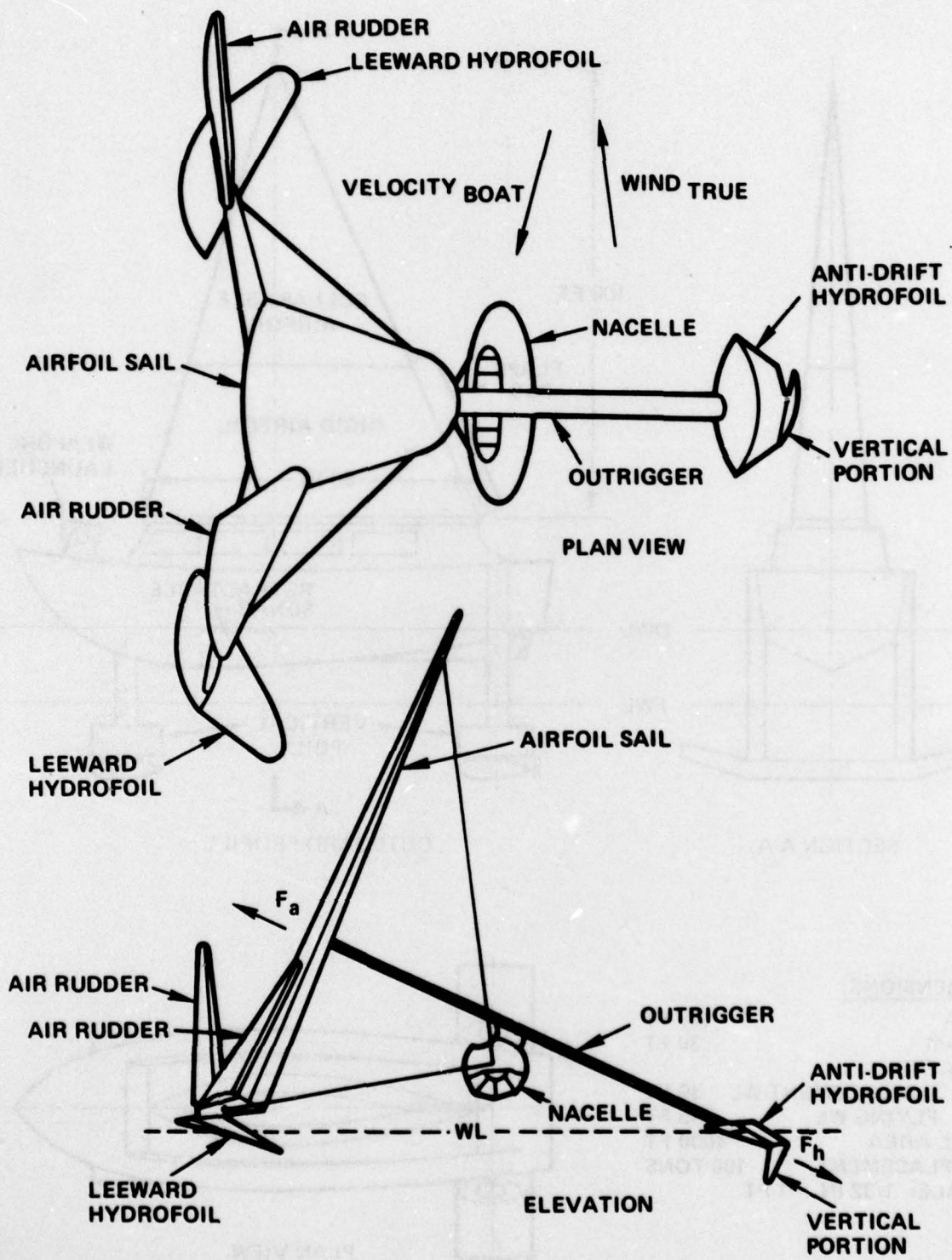
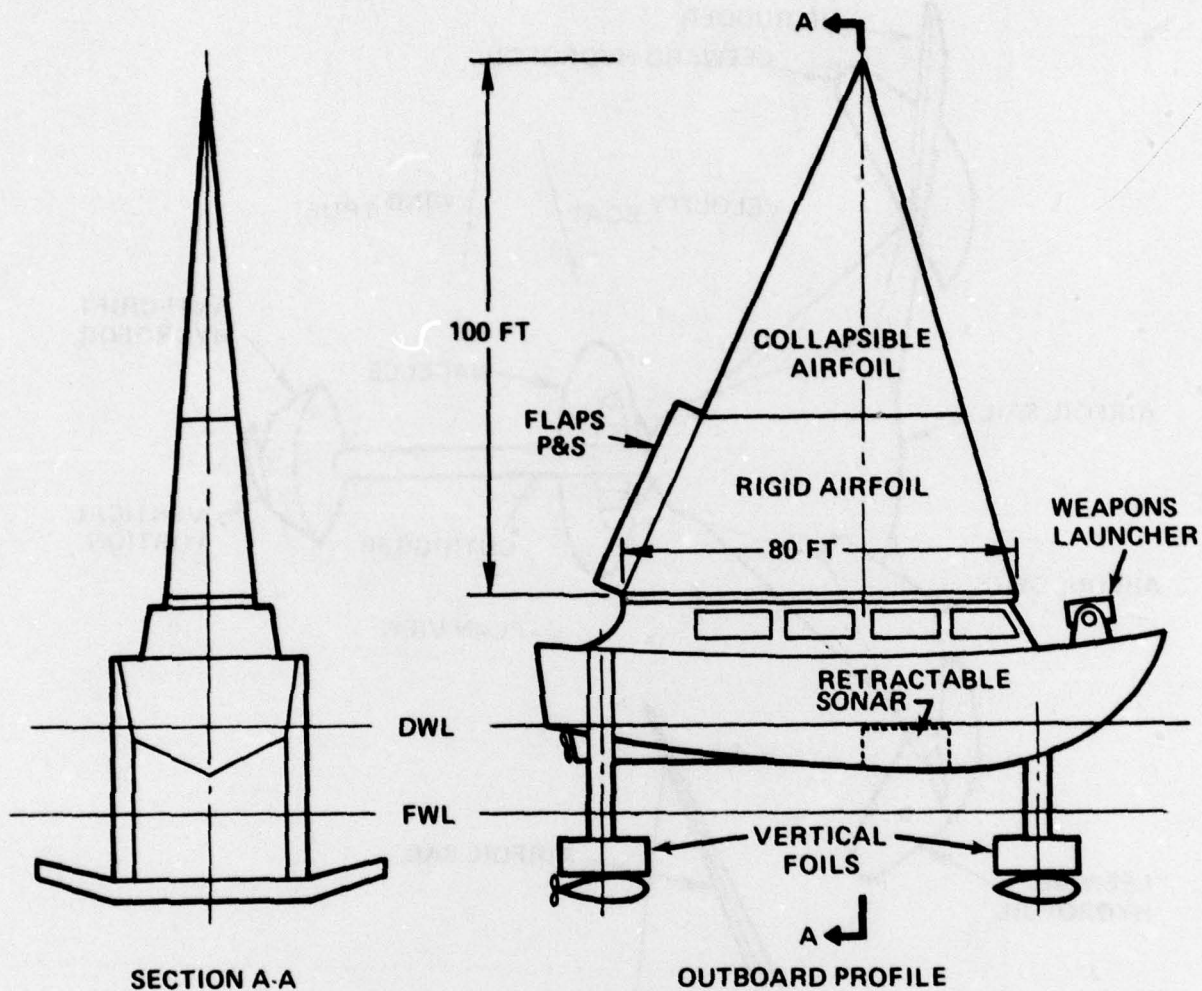


FIGURE 3 - PRACTICAL AEROHYDROFOIL (1)



DIMENSIONS:

LOA	120 FT
BEAM	30 FT
DRAFT:	
DISPLACEMENT WL	30 FT
FLYING WL	15 FT
SAIL AREA	4000 FT
DISPLACEMENT	100 TONS
SCALE: 1/32 IN. = 1 FT	

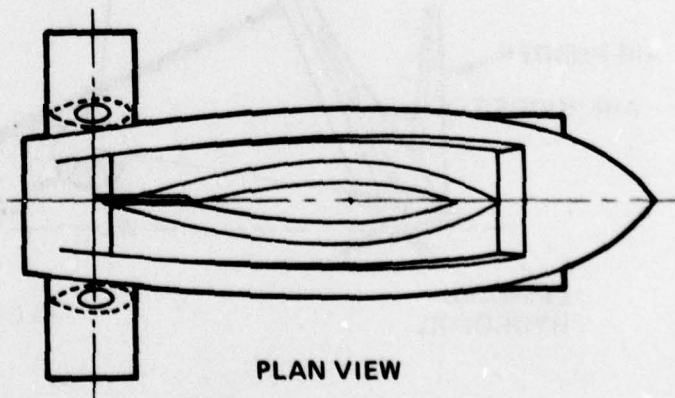


FIGURE 4 - SAILING HYDROFOIL

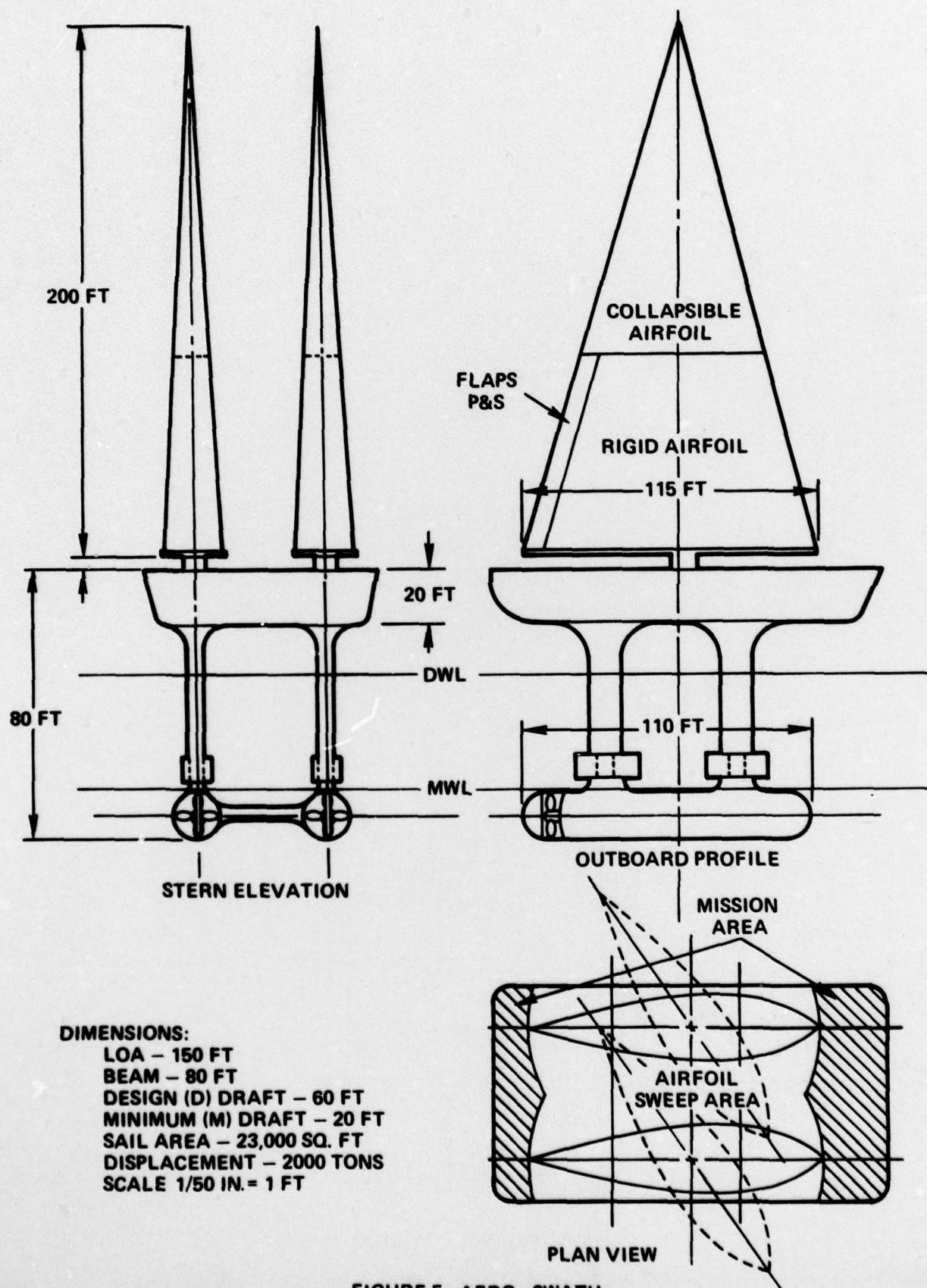


FIGURE 5 - AERO - SWATH